George Green: An Enigmatic Mathematician

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The mathematics developed by George Green has been widely applied in modern physics and quantum electrodynamics yet his life has remained something of a mystery. There is no reference to him in the main volumes of the *Dictionary of Scientific Biography*: he is belatedly and briefly included in the *Supplement* of 1976. The bicentenary celebrations of his birth in 1993 focused increasing attention on the man who gave the world Green's functions.

This MONTHLY has already published an authoritative account [**3**] of Green's first and seminal publication, *An Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism*, which examined in some detail his use and development of mathematical sources. What is presented here is a short survey of Green's life and an examination of the circumstances and the social environment in which he lived. The great problem is the lack of material concerning Green. His output was small; ten papers including the *Essay*, written in the space of eleven years, amounting to less than 250 pages of print. There are no manuscripts, no working papers, no diaries, no memorabilia. There are a dozen letters to his patron, but no replies. There is no portrait or photograph. There was no established family house for his common-law wife, Jane Smith, and their seven children, and when the last, Clara, died in 1919, the family was thought to be extinct.

The few official facts of Green's life were established and published by H. G. Green (no relation) [**5**]. His paper included two valuable letters written in 1845 by Green's cousin and brother-in-law, William Tomlin, and Edward Bromhead, his patron. In the 1970s Green's letters to Bromhead came to light—the only information extant in Green's own hand, the only testimony to his mathematical thought and the only revelation of his personality. Green died at the age of forty-seven, just at the time when his work was about to be recognized: in consequence he established no reputation in his lifetime.

Green was born in 1793 and died in 1841. He was the only son of a Nottingham baker, who prospered sufficiently to extend his bakery business and build his own mill in the nearby village of Sneinton. Later he built a family house next to the mill; he acquired further property and died in 1829, sufficiently affluent to allow his son George to live on his income for the rest of his life. At fourteen George was apprenticed to his father's mill manager, William Smith, father of Jane. He found his duties as a miller "irksome" but as the only son he was obliged to work for his father. By the age of eight he had shown a passion for mathematics, such that his father sent him to an expensive town school, Robert Goodacre's Academy, but he left the following year and started work in his father's bakery.

Nothing more is known of George Green's life for certain until he reached the age of thirty and became a member of the Nottingham Subscription Library. No other serious library facilities existed in Nottingham at this period, but the Subscription Library was in effect a gentlemen's club, housed in the elegant

Georgian Bromley House in the Market Square. The members owned the property, purchased books according to their taste, and confined their numbers to prosperous and "respectable inhabitants of the town" drawn from the professional classes, the gentry, and successful men of business. George Green, a working miller, and an artisan who worked with his hands, was an unlikely member of such a gathering. But apparently he was becoming known in the town for his mathematical interests; in any case he was probably sponsored by his cousin William Tomlin, a successful man of property and an active member of the Library. Five years later Green produced his first and most important work, *An Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism.* Green published the *Essay* at his own expense and opened a subscription list—a usual procedure at this period. As Bromhead wrote in 1845, "I met with a subscription list, for his first mathem1. publication, and added my name as Country Gentlemen often do by way of encouraging every attempt at provincial literature" [**4a**]. So Sir Edward Bromhead, of Thurlby Hall near Lincoln, became one of the fifty-one subscribers to the *Essay*, half of whom were members of the Library.

The *Essay*, which as far as is known was Green's own unaided work, was one of great originality, bu tit attracted little attention at the time and Green despondently resumed his milling. The death of his father, and his consequent independence, was followed by his first meeting with Bromhead in 1830, who encouraged him to resume his studies. Green wrote three papers, two on electricity and magnetism (which Bromhead sponsored for publication in the *Transactions* of the Cambridge Philosophical Society), and the third on hydrodynamics in the *Transactions* of the Royal Society of Edinburgh, of which Bromhead was a Fellow, as he was of the Royal Society of London. The period 1830 to 1833 produced Green's letters to Bromhead. The two men, despite difference in rank, were similar in age and had much in common in matters mathematical, since Bromhead had a strong interest in mathematical analysis. At Cambridge he had met his lifelong friends Charles Babbage and John Frederick Herschel, and they, with George Peacock and a few others, had formed the undergraduate Analytical Society in 1812, with the aim of publicising, in Cambridge, the continental mathematics deriving from Leibniz, in preference to the 'fluxions' of his contemporary, Isaac Newton, now deified in Cambridge. This led to the publication in 1816 of their translation of Lacroix's *Traité du calcul différentiel et du calcul intégral.*

Finally, in October 1833, Green enrolled as an undergraduate in Bromhead's college of Gonville and Caius, usually referred to as 'Caius.' In January 1837 he took his mathematical examinations and emerged Fourth Wrangler. (Wrangler was the Cambridge term for first class honours men, whose names were at that time published in order of merit, the Senior Wrangler being the first, and the last being awarded the Wooden Spoon.) In the following two and a half years, Green published his six final papers in the Cambridge *Transactions*. These, like the Edinburgh paper, dealt with wave theory based on studies in hydrodynamics, sound, and light. Six years after coming to Cambridge, Green was elected a Fellow of Caius, a position that would have allowed him to stay on in Cambridge, studying, writing, and consorting with Cambridge academics. Tragically, after holding his Fellowship for only two terms, he returned in failing health to Nottingham, "with the opinion," William Tomlin relates, "that he should never recover from his illness and which became verified in little more than a year's time on 31st May 1841" [**4b**]. Green's grave in St. Stephen's churchyard, Sneinton, is just across the road from the mill where he had worked for nearly twenty years.

Green's death in Nottingham caused little stir. His Fellowship had been noted in a single sentence in the *Nottingham Review* and on his death it contributed a modest obituary which concluded: "Had his death been prolonged, he might have stood eminently high as a mathematician." It would appear that Cambridge did not long hold Green in memory either. Four years after his death, an enquiry to Caius College was passed to Bromhead, which elicited his and Tomlin's letters of 1845. The enquiry produced more than the information contained in the letters, however, invaluable though that has proved, since it led to the retrieval of the long-neglected *Essay* of 1828.

The re-discovery of the *Essay* is one of the better-known incidents in the Green story and is recounted in the biographies of both Kelvin [**11**] and Liouville [**7**]. William Thomson, the future Lord Kelvin, took his degree in January 1845 and left for Paris to spend the summer working with Victor Regnault in his 'cabinet de physique,' and with letters of introduction to the mathematicians then in Paris: Liouville, Chasles, Sturm, and others. Thomson was already keenly interested in the problems of electricity and magnetism and he was first alerted to the existence of Green's *Essay* by a footnote in a paper on integrals by Robert Murphy. Murphy had been a Fellow of Caius during Green's residence there. He had also been the 'rapporteur,' or referee, of Green's paper on ellipsoids, sent in 1833 by Bromhead to Whewell, for publication in the Cambridge *Transactions*, and Green had sent a copy of his *Essay* with the paper. Murphy's footnote was as follows:

> The electrical action in the third section, is measured by the tension which *would* be produced by an infinitely thin rod, communicating with the electrical body, by the attraction or repulsion of the matter; it is what Mr. Green, of Nottingham, in his ingenious *Essay* on this subject, has denominated the Potential Function [**8**].

Thomson immediately visited the Cambridge booksellers. Not surprisingly, they knew nothing of an *Essay* published privately in Nottingham eighteen years previously. Just by chance however, on the eve of his departure for Paris, Thomson met his tutor, William Hopkins, who passed him two copies of the *Essay*, which Green had given him. (A later paper, inscribed "W Hopkins Esquire" in Green's hand, is now in the Green Archive, in the University of Nottingham.)

"I had only time that evening to look at some pages of it, which astonished me," wrote Lord Kelvin in 1907, a fortnight before he died at the age of eighty-three. "Next day, if I remember right, on the top of a diligence on my way to Paris, I managed to read some more of it" [**4c**].

Green's *Essay* caused a sensation among the mathematicians in Paris. In it they found Green's solutions to the problems then confronting them. The *Essay* was published by Crelle in his *Journal* in three parts in 1850, 1852, and 1854. By 1900, as noted by Grattan-Guinness, Green's functions, referred to as such by Burkhardt and Meyer [**1**] and keenly propagated by Riemann and Neumann, were well known to German mathematicians. The *Essay* was not reprinted in England until 1871, in *Mathematical Papers of the late George Green*, edited by N. M. Ferrers, promoted by Caius College and printed in London.

William Thomson did more than re-discover the *Essay*. He developed a life-long admiration for Green and did much to establish his posthumous reputation. He further developed Green's theories in his own research in electromagnetism, e.g., his method of images. His friend G. G. Stokes likewise developed Green's work on

wave theory in his own studies in hydrodynamics. Green's considerable influence on the development of nineteenth century classical physics is summed up in the words of Edmund Whittaker [12]:

> It is no exaggeration to describe Green as the founder of that 'Cambridge School' of natural philosophers of which Kelvin, Stokes, Rayleigh, Clerk Maxwell, Lamb, Larmor and Love were the most illustrious members in the later half of the nineteenth century.

It was through the work of Julian Schwinger and Freeman Dyson, in the mid-1940s, that Green's mathematics is now used in quantum electrodynamics. His physical concepts have found their way into various branches of modern physics and are applied in many different technologies. It is part of Green's tragedy not only that he died at the time his work was about to achieve recognition but also that he died without any awareness or indication of his future greatness. There had been but one gleam of what might have been vouchsafed him in the way of a possible European reputation in his lifetime. In the mid-1970s there came to light copies of Green's papers of 1838 and 1839, now in private hands, inscribed by Green to "Prof. Jacobi from the Author"—Green's usual inscription. Jacobi in Königsberg

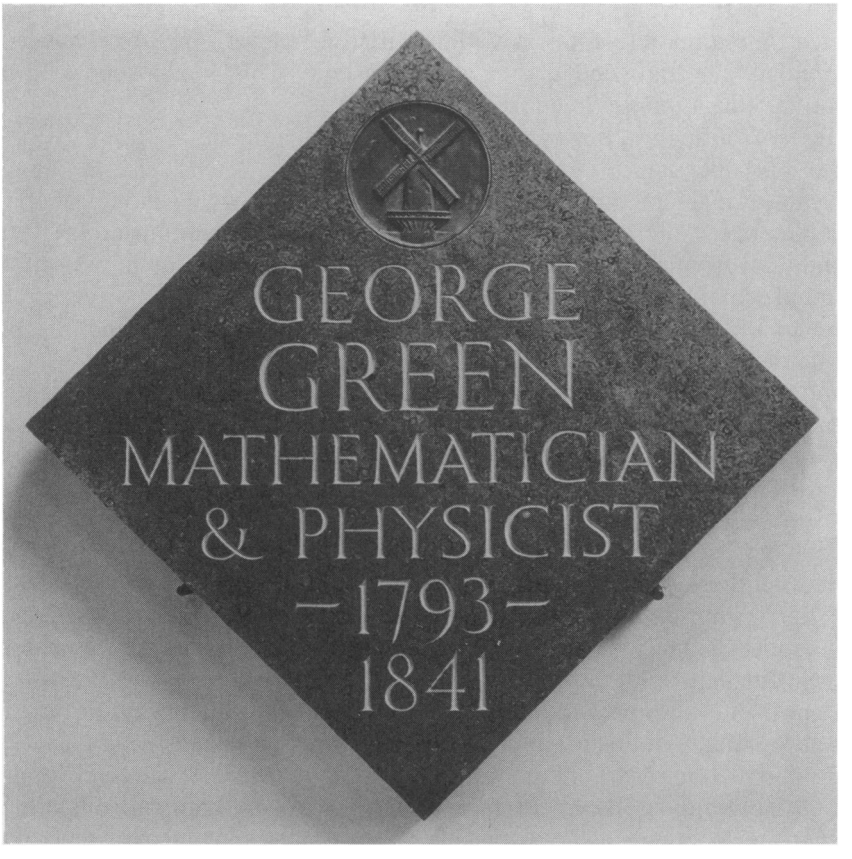

Figure 1. Plaque to George Green in Westminster Abbey, London, dedicated in July 1993 on the bicentenary of his birth.
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was a regular recipient of the Cambridge *Transactions*. One wonders how Green came to send him extra copies. He would not have sent the papers unsolicited; he had neither the academic nor the social standing to do so, nor would it have been his nature.

These then are the bare bones of Green's story. Some knowledge of early nineteenth century social history and of conditions in Nottingham provide a tentative reconstruction of his environment, but how well did Green's little-known personality fit into it?

To what extent did Green's family circumstances produce or foster his genius? His grandfather was a farmer whose family had for generations worked the same acres north of Nottingham. His father, George Green, apprenticed to a baker in Nottingham, later married his employer's daughter and set up his own business nearby: nothing much here to suggest mathematical genius. On the other hand, his cousin, William Tomlin, refers to a "strong inclination for as well as a profound knowledge in the mathematics," as a result of which Green's semi-literate father in 1800 sent him to Goodacre's Academy. Young George would normally have been sent for a few terms to a 'writing school' where tradesmen's sons were taught at little expense the rudiments of reading, writing, arithmetic, and bookkeeping. In Nottingham in 1800 more general opportunities for learning were not available to the children of artisans and the poorer classes, until religious and national organisations started setting up schools in the 1830s and 40s. It says much for Green Senior that he was prepared to spend good money on his son's education, but after four terms George was withdrawn from school, since his knowledge of mathematics "far transcended that of his masters." This would appear to be the only formal education George Green ever received.

Goodacre's influence, however, may have been significant [**2**, pp. 17–23]. He was proud of his collection of "Philosophical Instruments," which included "an electrical machine," magnetic apparatus, and an orrery, or working model of the solar system. Goodacre later became a lecturer in popular science, touring England and Scotland, and from 1824 to 1827 he gave lectures on astronomy in major cities in the United States. His enthusiastic demonstrations may well have aroused Green's interest in physical phenomena, and particularly in electricity and magnetism, which he developed later in the *Essay*.

A more clearly defined influence comes from a book published by Rev. John Toplis, who in 1806 arrived from Cambridge as headmaster of the Nottingham Free Grammar School. This was a translation of the first book of the *Mécanique Céleste* of Laplace published in 1799. Toplis had been ranked Eleventh Wrangler in 1802 and had subsequently been appointed Tutor and Fellow of Queens' College. Like Bromhead and his friends in the Analytical Society a decade later, he was an enthusiastic convert from the Newtonian fluxions taught in Cambridge to the Leibnizian-based mathematical analysis widely used on the Continent. Toplis published the book at his own expense in Nottingham in 1814—a lone cry in the Nottingham wilderness, but one heard by George Green. Here surely lies the origin of the "Mathematical Analysis" in the title of his *Essay*. In his Preface Toplis recommends the study of other French mathematicians, Lagrange, Legendre, and Lacroix, all of whom are quoted by Green in his text. Green even echoes the final paragraph of Toplis' Preface in his own—a plea for the reader's indulgence for shortcomings in the work, due to the distractions of their daily occupations. Toplis' book was on sale at the Nottingham booksellers and Green obviously studied its contents. An intriguing question now arises: did the author actually

teach him? Green would have been about fourteen and starting his apprenticeship as a miller when Toplis arrived in Nottingham. He returned to Queens' in 1819 when Green was twenty-six. The Free Grammar School with its resident headmaster was less than five minutes' walk from the Green family home. Given each their passion for mathematics, quite apart from social factors such as living in the same neighbourhood, it seems quite possible that Toplis could have been Green's mentor, an interesting hypothesis for which there is only circumstantial evidence.

Apart from Goodacre and Toplis, there appears to be no further influence on Green's development until he joined the Nottingham Subscription Library in 1823. In his daily work in the mill, however, Green was well aware of the mathematics underlying its construction and mechanics. In 1828 a self-important minor mathematician from London visited Nottingham: "I heard of a young miller [Green was thirty-five!] of the name of Green, who had been printing a quarto, in which he had investigated with La Place-like precision the laws of supposed electrical action." Sir Richard Phillips was scathing on the question of contemporary physics —on "Ivory's waste of time about imaginary capillary attraction, and La Place's whimsical speculations about gravific atoms," and regrets that "Mr. Green has spent so much ingenuity in misapplying his sound mathematical learning upon it" **[10]**. Sir Richard does condescend, however, to admire Green's mathematical calculations: "His sails have a radius of twelve yards and revolve twenty-five times a minute, or more than a mile at the extremities. This great velocity carries round the stones, which are sixteen feet in circumference, 162 times a minute . . . ," and so on. Green's response to this visit can only be imagined: he may have wondered whether, in meeting Sir Edward Bromhead two years later, he would encounter a second Sir Richard Phillips.

As a member of the Bromley House Library, Green entered a world different from the one he knew. It helped both his intellectual and social development. Intellectually he was in a class of his own; in five years he would publish the *Essay*. What must be borne in mind, however, is that Green was not the usual gentleman-scholar of the period. He had neither the leisure nor the education. He was a working miller with ageing parents, a growing family, and considerable business responsibilities. It is reasonable to assume, however, that he was already familiar with the work of the French analysts advocated by Toplis. He would have absorbed much of the physics with the mathematics and appears to have fastened onto electricity and magnetism as topics for further study. So what had the Nottingham Subscription Library to offer?

Of the few titles listed under Natural Philosophy in the Library, it is unlikely that any would have been of use to Green, since at this stage he was virtually at the cutting edge of continental science in his particular field and would shortly produce his functions and his Theorem. The current taste lay in Moral Philosophy, in literature, history, theology, travel, and biography. The dozen or so books, listed under Natural Philosophy—such as Hutton's *Course of Mathematics* of 1798 and Gregory's *Treatise of Mechanics* of 1806—were written by professors at the Royal Military Academy at Woolwich and served primarily as textbooks for their students. These were doubtless helpful to some of the Library members, but it was Biot's *Traité de Physique* of 1816, relating the recent experiments in electricity of Coulomb, which Green found more useful and which he must have acquired independently. What he undoubtedly found useful were the *Transactions* of the Royal Society of London. It is obvious both from the Preface to the *Essay* and his letters to Bromhead that Green trawled through the *Transactions*. (Unfortunately

for Green, the Library did not subscribe to the *Philosophical Magazine*, which he would have found helpful, but which he had probably never heard of, the Library members preferring to read the more popular *Gentleman's Magazine* instead.)

Green's primary sources for the "Theories of Electricity and Magnetism" discussed in the *Essay* were the memoirs of Poisson. Those on electricity were published by the Institut de France in 1811 and 1812; the first of several on magnetism by the Académie des Sciences in 1821. The questions inevitably arise: how did Green in his isolation in Nottingham know of their existence and where did he find them? The answer to the first is straightforward, since they were listed in the "Presents" recorded in the annual *Transactions* of the Royal Society, to which Green had access in the Library. But where did he find them? Booksellers could order published texts, but memoirs? There were copies available to Fellows in the Library of the Royal Society in London and it was possible for Fellows to accompany, or provide a suitable letter of introduction for, a non-member. This appears to be the only way that Green would have had access to Poisson's memoirs on electricity—two memoirs "of singular elegance which to be duly appreciated [sic] must be read," states Green in the Preface to his *Essay*, and this would be no idle statement on his part. There was one Fellow of the Royal Society in Nottingham at this time. Dr. John Storer had been the first President of the Bromley House Library from 1816 to 1821 and was a well known local figure. Earlier he had been instrumental in setting up the new Lunatic Asylum in Sneinton, where old George Green was by then a prosperous miller and a churchwarden of St. Stephen's. Could Dr. Storer have provided George Green with a letter of introduction to the Librarian of the Royal Society?

Another source lies in the abstracts published in the scientific journals. The Library subscribed to three such journals prior to 1828. An entry in the minutes of 1825 records a decision to subscribe to Brewster's *Edinburgh Journal of Science*, founded the previous year, and it may be presumed that Thompson's *Annals of Philosophy* and the *Quarterly Journal of Science and the Arts* had been taken from an earlier date. The latter published in 1824 an extended extract in translation of Poisson's memoir on magnetism of February of that year and read to the Royal Academy of Science, and also a second, in 1825, of a further extract of his memoir of December 1824, though it is the earlier memoirs of 1821 and 1822 to which Green makes more frequent references in the *Essay* [**9**]. Presumably he already had access to these, as he had to the earlier memoirs on electricity. Apart from the memoirs of Poisson, it would appear that Green's knowledge of earlier writing on electricity and magnetism was otherwise confined to the few papers in the Royal Society *Transactions*. He opens the *Essay* with a reference to Cavendish's paper on electricity of 1771 (in which he identifies and corrects an unsatisfactory proposition), but as "[L]ittle appears to have been effected in the mathematical theory of electricity" since then, he moves straight to Poisson's Memoirs of "about 1812."

A more subtle influence on Green's development may be found in the community and activities of the Bromley House Library itself [**6**], [**2**, pp. 43–58]. Green's five years' membership of the Library up to 1828, and his association with its more academic and professional members, would have provided a valuable contrast to his normal working life and his contacts with tradespeople and labourers. The Library's second President, Rev. White Almond, was, like Toplis, a mathematics graduate from Queens' Cambridge; they were both local men of similar age and their lives in Nottingham overlapped from 1814 to 1819. Almond was a member of the Royal Astronomical Society; he owned a telescope and was an eager participant in the Debating Society, which also met in Bromley House. Dr. Alexander

Manson was a Fellow of the Royal Society of Edinburgh and one of the town's leading physicians; he pioneered the use of iodine in surgery. There were several clergymen, either in benefices or proprietors of schools. The Library had been formed primarily for the edification of its members, but it soon became the town's centre of culture and scientific interest. It sponsored lectures, enlivened by models and demonstrations, on chemistry, electricity and magnetism, mechanics, and astronomy, and it hosted itinerant lecturers, of whom Robert Goodacre became a successful example. In response to growing working class aspirations and demands for education, the more philanthropic members of the Library were instrumental in setting up the Mechanics Institute in 1824 and later the 'Artizans Library.' Green's membership thus coincided with a period of considerable interest in the promotion of popular scientific knowledge, which possibly accounted for the support of the twenty-five members who subscribed to the publication of his *Essay*.

Green, with a modest local reputation but no influence, contacts, or sponsor, followed the example of Goodacre (with whom it would appear he may have kept in touch), and Toplis (whom he may have got to know quite well), and published his work at his own expense. He knew well what he was doing and realised only too clearly his position. As he wrote to Bromhead in 1830:

> Indeed the trifle [the *Essay*] would never have appeared before the public as an independent work if I had then possessed the means of making its contents known in any other way but as I thought it contained something new and feared that coming from an unknown individual it might not be deemed worthy of the notice of a learned society I ventured to publish it at my own risk feeling conscious at the same time that this would be attended with certain loss **[4d]**.

The title page announces that the *Essay* was printed for the author by T. Wheelhouse, and sold by various booksellers in London, Cambridge (Deighton's), and Nottingham. By this date, such information was possibly a token insertion for local prestige. The London and Cambridge firms were the agents for supplying books ordered by customers at the Nottingham booksellers and printers (often the same people), but it does not imply automatic or reciprocal distribution of published texts. The *Essay* is not listed in Deighton's catalogues, and nearly twenty years later, as William Thomson found, they had not heard of it. As for publicity, notices in the *Nottingham Journal* and the *Nottingham Review* produced fifty-one subscribers, all but half a dozen from Nottingham.

All these considerations make a sad case for Green but, with his daily responsibilities of work and family, and with his lack of informed academic and social contacts, it is difficult to see what he could have done in his circumstances. At least he had the initiative, and fortunately the finance, to go for private publication.

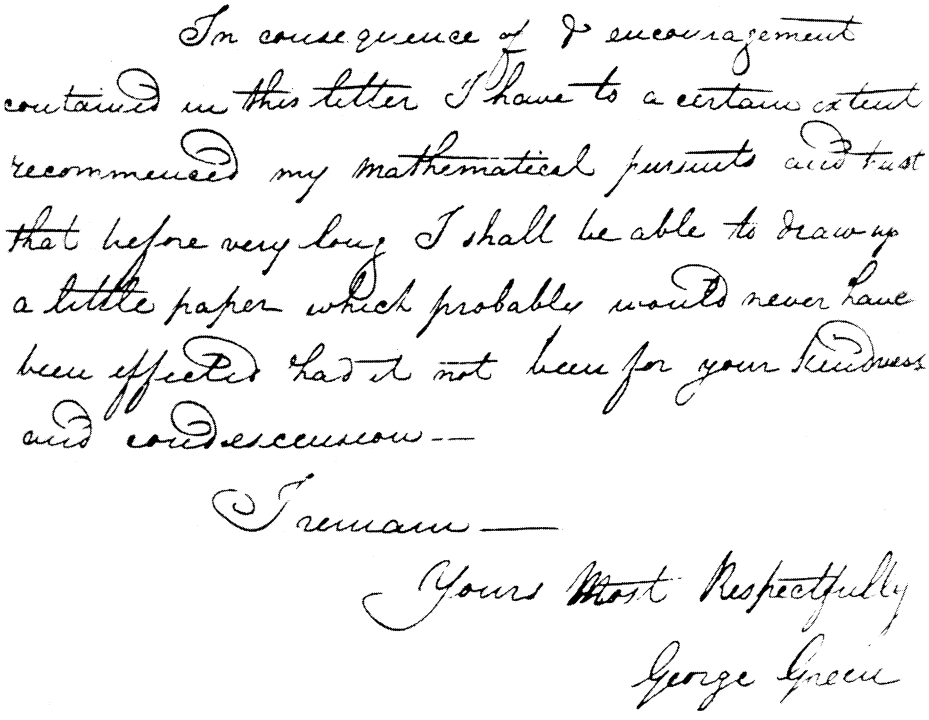
It was the "Mathematical Analysis" in the title of Green's *Essay* that presumably provoked Bromhead's interest, in view of his Cambridge experiences. Green sent Bromhead his copy on April 19th 1828 with a note of thanks and appreciation. The only extant example of Bromhead's participation in the correspondence is the draft of a reply, found among his letters, offering to sponsor the publication of any further papers in one of the learned societies since, as he wrote in 1845, he realised the *Essay* "must be a complete failure and dead born." It was nearly two years before Bromhead received an answer to his offer, which, apart from the brief note sent with the *Essay*, was the first letter of the dozen Green would write in the

next four years:

> Sneinton near Nottingham Jan 19th 1830
>
> Sir
> From some observations made to me last Saturday by Mr. Kidd of Lincoln I find that I have unintentionally been guilty of a gross neglect on an occasion where of all others I would most carefully have avoided it and therefore hope you will pardon the liberty I am about to take in endeavouring to explain the circumstance of my not having answered your very obliging and condescending letter and this explanation I am the more desirous to enter into because nothing connected with the publication of my little Essay has afforded me so much satisfaction as that it should have been found in any degree worthy of your notice.
> Had I followed my own inclination I should immediately have written in order to have expressed in some measure my gratitude for the very handsome offer with which you had honored me but on mentioning my intentions to a gentleman on whose opinion I had at an early age been accustomed to rely he assured me that no answer would be expected but that on the contrary it would be considered as a liberty to trouble one so much my superior farther until I should be able to avail myself of your kind offer by forwarding some memoir to be communicated to one of the Royal Societies and as this gentlemen had seen more of the world than myself I yielded to his opinion though with reluctance lamenting at the same time that custom should compel me to act in a way so much at variance with my own feelings.
> Although from a mistaken notion of propriety I have been so long hindered from making any acknowledgement for the very handsome offer you were so kind as to make I trust you will do me the justice to believe that I have felt most sensibly the honor conferred upon me by so much condescension on your part and that I have always esteemed that offer as most valuable **[4d]**.

Green then continues by describing his dilemma regarding publication, as quoted earlier, and finishes by promising to send a paper, a promise he confirms in his next letter of 13 February. The gentleman whose misguided advice Green followed was probably Robert Goodacre, recently returned from his American lecture tour; Mr. Kidd of Lincoln has proved unidentifiable.

Green visited Bromhead at Thurlby Hall, and his subsequent letters record the writing and publication, sponsored by Bromhead, of the three papers on topics associated with the *Essay* already mentioned. With this encouragement Green's aspirations grew. It would appear from both Tomlin's and Bromhead's letters of 1845 that Green had for some time been considering, at the suggestion of "[S]everal kind and respected friends" that "he should adopt an University education." Green first raised the issue with Bromhead in April 1833 and by the following June had made up his mind. Bromhead offered sponsorship to his own college and on October 1st Green entered Caius College, Cambridge. This was not an easy decision for Green. He could now sell the milling business, while retaining ownership of the mill, and live on his income. He could establish Jane Smith and their four children nearby and use the rents of the family house and mill as additional finance. But entry to Cambridge and the acquisition of a degree presented considerable hurdles to be overcome. Apart from social disadvantages (when four years later he graduated, as Fourth Wrangler, his success was recorded


In consequence of the encouragement contained in this letter I have to a certain extent recommenced my mathematical pursuits and trust that before very long I shall be able to draw up a little paper which probably would never have been effected had it not been for your kindness and condescension—

I remain—

Yours Most Respectfully

George Green

Figure 2. Concluding paragraph of Green's second letter to Bromhead of 13 February 1830: *In consequence of the encouragement contained in this letter I have to a certain extent recommenced my mathematical pursuits and trust that before very long I shall be able to draw up a little paper which probably would never have been effected but for your kindness and condescension—I remain—Yours most respectfully —George Green.*

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by Romilly, a celebrated Cambridge diarist as "Green of Caius (son of a miller) who was expected to be Senior Wrangler but was only fourth)," his lack of formal education was a further disadvantage. All graduates had to pass examinations in Latin and Greek before proceeding to the third year degree course, elementary enough for young twenty year olds, ex-pupils of grammar and independent schools or private home tutors, but for Green a considerable obstacle. Among some old mill accounts was found one scrap of paper in Green's writing unrelated to mill business—"*Cesar scribere et legere simul dictate et audire solebat*" (Caesar was accustomed at the same time to write, read, dictate, and listen)—poignant evidence of Green's slow climb to some level of classical literacy. His cousin William Tomlin summed up the situation when recalling Green's attendance at Goodacre's Academy:

> His schoolmasters soon perceiving this strong inclination for as well as profound knowledge in mathematics and which far transcended their own, relinquished the direction of his studies and in consequence his literary acquirements were not properly promoted: in this respect, he had when contemplating the probability of going to the University to pay some attention in his more mature years [**4e**].

This problem still loomed large in Green's mind in 1833. He wrote to Bromhead in April: "...you are aware that I have an inclination for Cambridge if there was a

fair prospect of success. Unfortunately, I possess little Latin, less Greek, have seen too many winters, and am thus held in a state of suspense by counteracting motives" **[4f]**. The following month he asked Bromhead which college he thought suitable "for a person of my age and imperfect Classical Attainments."

Bromhead did not confine his partronage of Green merely to recommending him to go to Caius College.

> I also gave him letters of introduction to some of the most distinguished characters of the University that he might keep his object steadily in view under some awe of their names and look upwards, not of course with any view of trespassing on the social distinctions of our University, in my time much more marked than at present, but that he might venture to ask advice under any emergency **[4g]**.

Green may not have needed Bromhead's letters other than to indicate his arrival in Cambridge. This again was a custom of the time. William Thomson in 1845 arrived in Paris with a dozen or so. In fact Green came already with something of a reputation. He had had one paper published in the Cambridge *Transactions* of 1833 "Communicated by Sir Edward French Bromhead, Bart. [Baronet], M.A., F.R.S.L. and E." and a second under his own name "George Green Esq., Caius College." This latter was against all precedent since the Cambridge Philosophical Society published papers only by graduates, unlike the *Cambridge Mathematical Journal*, which included papers by undergraduates, such as William Thomson, and outsiders, such as George Boole.

Green soon raised the expectation of being the Senior Wrangler of his year (as would William Thomson, though he came second in 1845), and he is noted by Harvey Goodwin in the first edition of the *Dictionary of National Biography* as "standing head and shoulders above all in and outside of the University." In January 1837, Green was Fourth, being beaten by three young men from St. John's College, including James Joseph Sylvester, pupils of the renowned coach John Hymers. William Hopkins, already mentioned as William Thomson's tutor, was another highly respected Cambridge coach who later became Professor of Geology. The Cambridge coaches took their students through all possible examination questions. Since the Wrangler's rank depended on the maximum number of questions answered and thus marks gained, without the necessity of giving much mathematical thought to the problem set, it is perhaps not surprising that in the event George Green, with his own brand of mathematical genius, did not gain first place.

Green stayed on in Cambridge awaiting election to a Fellowship. As a graduate he could now become a Fellow of the Cambridge Philosophical Society. During the two and a half years' interval he wrote and published his six further papers on wave theory in the *Transactions*—on one occasion at least reading a paper at the same meeting as William Whewell. He was now working in the main stream of Cambridge—and indeed European—research, as the papers sent to Jacobi and references to a younger generation of French scientists, such as Fresnel and Cauchy, would suggest. In the light of his current research, it is perhaps not surprising that Green appears to have given little thought to the *Essay* of nearly twenty years earlier, despite his quiet distribution of copies to Hopkins and to the Cambridge Philosophical Society and Caius College Libraries. As it was, Thomson's youthful enthusiasm ensured re-publication of the *Essay* on the Continent, but he confessed to a lifelong regret that as editor he had not thought to reprint the *Essay* in

the *Cambridge and Dublin Mathematical Journal*, successor to the *Cambridge Mathematical Journal* **[4h]**.

Green's last recorded letter to Bromhead is dated May 22nd 1834, written in the middle of his first year examinations. After discussion of the publication of his second paper, published the following year, he concludes:

> I am very happy here and I fear too much pleased with Cambridge. This takes me in some measure from those pursuits which ought to be my proper business but I hope on my return to lay aside my freshnesses and become a regular steady Second Year man **[4i]**.

This appears to be the last written communication between the two men, though Green may have visited Bromhead at Thurlby in vacations. The latter may have thought his obligations as patron were discharged. Certainly in his letter of 1845 he makes no reference to events in Cambridge other than mentioning the letters of introduction and concludes abruptly and rather disconcertingly:

> So much for my knowledge of poor Green, but I have written to a gentleman in Nottingham, who may perhaps supply further particulars . . . .

This led at one remove to William Tomlin's letter of the same date. But a closer look at the custom of patronage in this period serves to put Green's situation in longer focus and at the same time allows readers to adjust perceptions of the personalities of the two men involved. Patronage was a long-established custom. The more enlightened patron took it as a responsibility of his social position, as Bromhead certainly did, in helping George Green, and later, the young Lincoln schoolmaster, George Boole. When Bromhead received his copy of the *Essay*, he had difficulty in phrasing his offer to sponsor the publication of any later papers, since he did not know the social status of the author. Realising that the Director of the Lincoln Lunatic Asylum, of which he was Vice-President, had Nottingham connections, he wrote to him for information. The answer re-assured Bromhead as to the propriety of his actions; at the same time it offers posterity a further account of Green's reputation in Nottingham at the time of the publication of the *Essay*:

> 1828
>
> Sir
>
> I learn from Nottingham that Mr G Green is the Son of a Miller, who has had only a common education in the Town, but has been ever since his mind could appreciate the value of learning immoderately fond of Mathematical pursuits, and which attainments have been acquired wholly by his own perseverance unassisted by any Tutor or Preceptor: he is now only 26 or 27 years of age of rather reserved habits attends the business of the Mill, but yet finds time for his favorite Mathematical reading—
>
> Your obt. Servant
> Thos Fisher
>
> Asylum May 10 **[4j]**

Conventional epistolary forms duly reflected the differences in social status. Thus Bromhead's apparent arrogance can be viewed as a natural assumption of superiority—and responsibility—and Green's apparent obsequiousness as a normal expression of respect to one "so much [his] superior." Bromhead found it easy to offer

help, but Green had difficulty in accepting it, as shown by his reply to an unexpected invitation from Bromhead:

> You were kind enough to mention a journey to Cambridge on June 24th to see your friends Herschell Babbage and others who constitute the Chivalry of British Science. Being as yet only a beginner I think I have no right to go there and must defer that pleasure until I shall have become tolerably respectable as a man of Science should that day ever arrive.
>
> I remain with the Greatest Respect
> Yours Sincerely
> Geo: Green **[4k]**

A modern reader might assume that the association between the two mathematicians had established a certain degree of equality. Not so, however. Bromhead's letter of 1845, mentioning the letters of introduction, and in particular, the final reference to "poor Green"—with the significant omission of title—reveals clearly enough the true situation, one reflected in the meeting of Green and Sir Richard Phillips, though with the overtones of ignorance and complacency absent in the case of Bromhead.

A more attractive feature of patronage was the factor of disinterestedness, since each side was activated by a common interest in science and each served its advancement. There are two interesting reflections of this approach in the Bromhead correspondence. In his third letter to Bromhead, written in May 1832, Green writes:

> I cannot conclude without expressing my gratitude for your kind assistance which can only have arisen from a liberal desire to forward the interests of science by encouraging even the most humble cultivators
>
> I remain with the greatest respect
> Yours Very Sincerely
> Geo: Green **[4l]**

Bromhead expresses the same sentiment in his letter to Whewell of November of that year when discussing editorial changes to Green's paper on the equilibrium of fluids:

> Would it be too great a favor to request that you would become Gardener in this pruning.... Mr. Green had retired in despair from mathematics and undertook this memoir at my request, from which you will see that a little encouragement may secure him as a Recruit to the very small troop who serve under the severe sciences... **[4m]**.

The story of Bromhead's patronage highlights Green's dilemma. Given his social status, his personal circumstances, his self-confessed limited knowledge of the world, and his lack of academic contacts, it seems evident that Green could never have made his way alone. Bromhead's patronage was vital to his work and intellectual advancement. Unfortunately both were cut short by Green's early death in 1841.

Green's posthumous reputation proved as varied and uncertain as his life. Reference has already been made to his lack of reputation in Nottingham and to his irregular family situation. These are closely linked. Green never openly

acknowledged the existence of Jane Smith and their seven children, though they were well provided for in his will, and, until his final return from Cambridge, Green and Jane Smith are not known to have lived under the same roof. Green died, however, in the house where Jane then lived at 3 Notintone Place, opposite St. Stephen's Church and a stone's throw from the mill. Mrs. Jane Green, as she had always been known, continued to live in the house after Green's death and was later buried in a grave adjoining his. Local hearsay reported that Green Senior had opposed marriage; later, Green's aspirations for Cambridge and a Fellowship dictated celibacy, since prospective Fellows had to be unmarried. Furthermore, Victorian society imposed a strict moral code under which illegitimacy was a social disgrace and Green's surviving children, Jane, George, Elizabeth, and Clara, while

Figure 3. Green's Mill in Sneinton, Nottingham, built in 1807 by his father, where George Green laboured for over twenty years. It was restored in 1985 as a memorial to him by the George Green Memorial Fund under its founder-chairman Professor Lawrie Challis.
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living comfortably, bore its stigma. Jane and Elizabeth married, but George, who took a mathematics degree at St. John's, Cambridge in his late twenties, was obliged to hide his identity so as not to compromise the memory of his father, and committed suicide in London at the age of forty—a further social disgrace at this period.

Only the youngest, Clara, remained, dying in the poor hospital in 1919 aged seventy-eight. She lies buried in a corner of the town cemetery and her forlorn and neglected grave was discovered only a few years ago. She inherited finally all of Green's once-prosperous estate of 1841, the mill, the family house, and land, together with property in Sneinton and Nottingham, but all had been heavily mortgaged and she left only debts. On her death the family was presumed extinct, and the Crown disposed of her effects. The mill was in a ruined state, not having been worked since the 1860s. It was restored to full working order in 1985 by the George Green Memorial Fund. Clara Green, a colourful and eccentric figure, reputedly lived in a hut in the garden of one of the Sneinton houses she owned and on her death neighbours cleared out all the rubbish and papers and burnt them. This could possibly account for the fact that none of Green's writings has survived.

One can now appreciate why Green's name and reputation were unrecognised in Nottingham until the restoration of his mill and the celebrations of the bicentenary of his birth in 1993. These culminated in the dedication of a plaque to Green in Westminster Abbey in London. This lies next to Newton's grave in the Sanctuary and in close proximity to similar plaques to Faraday, Kelvin, and Clerk Maxwell. The celebrations were attended by fourteen blood descendants of George Green, two from Canada and one from New York, with members of their families, twenty five in all. This surprising twist to the Green story is explained by the fact that Green's eldest daughter Jane, the only one of the seven children to have offspring, left one son, George Green Moth. His six children were born in two marriages, at forty years' interval, and the two families, who grew up in ignorance of each other's existence, were traced in the 1970s and 80s. They were united for the first time in Nottingham at the Civic Service of Thanksgiving in St. Stephen's Church on 13 July 1993, the eve of the bicentenary of their ancestor's birth.

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